

Chapter 9C4. Focal Taxonomic Collections: Peracaridan Crustaceans

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Summary

No clear peracaridan NIS were discovered among the scores of species collected in three surveys of 72 sites in 21 general areas of Prince William Sound and south central Alaska between 1997 and 1999. No NIS were found in UAF samples from the area collected previously. Two peracaridan species previously considered to be introduced are likely to be misidentified. Five species of NIS gammaridean amphipods were found in ballast water of tankers travelling to Prince William Sound, indicating that this is an active mechanism of NIS transport to Alaska, even though they do not appear to have invaded or become established there. Invasions of Alaskan estuaries and marine waters by a broad diversity of peracaridan species have not occurred. The diversities of peracaridan NIS invasions in the northern hemisphere vary with climate, as do invasions by other taxa noted previously. Most marine and estuarine peracaridan NIS thus appear to be incapable of invading Alaska from lower latitudes due to the extreme climate. The risk of invasions by high diversities of NIS of peracaridans thus appears to be extremely low.

These findings do not indicate whether a few NIS could be present at ecologically catastrophic abundances, however. Eight peracaridans that are prominent members of either fouling or benthic communities sampled in the survey, have unclear origins or cannot yet be clearly distinguished from species that are nonindigenous to the northeast Pacific. They are therefore classified as cryptogenic. These cryptogenic peracaridan species occur in the same areas as the soft shell clam, *Mya arenaria* Linnaeus, 1758, which is one of the most clearly documented NIS in south central Alaska. If proven to be NIS, these cryptogenic peracaridan species, would be evidence that even a few NIS capable of invading Alaskan estuaries can increase to ecologically catastrophic densities. They would indicate that surveys of peracaridan NIS diversity, such as this one, are an insufficient basis for estimates of risk. Whether these peracaridan crustaceans are, in fact, native to the region therefore should be tested by analyses of morphological variation, molecular genetics and by crossbreeding viability tests with their presumed original populations.

Introduction

A major objective of the south central Alaskan NIS survey was to determine whether introductions of marine or estuarine species have already occurred. An ultimate objective of the overall risk analysis is to predict whether Alaskan waters are vulnerable to NIS invasions. The survey results and comparisons of climate effects on peracaridan NIS diversity over the northern hemisphere provide a basis for this prediction.

Predicting which nonindigenous species (NIS) can be introduced, where, and the factors that control their survival are major objectives of invasion ecology. These predictions require knowledge of the interactions between dispersal and processes that determine NIS survival. The

mechanisms of NIS dispersal among estuaries are becoming well known (*e.g.*, Cangelosi 1999, Cohen 1998, Frey et al. 1999, Draheim and Olson 1999, Miller and Chapman 2000, Moy 1999, Ruiz et al. 1999, Thresher 1999), while the processes limiting NIS survival and production among estuaries remain poorly known. The distributions of NIS reveal how survival varies as dispersal occurs and thus indicate the interactions of dispersal, ecology, and survival. Interpreting the geography NIS distributions is thus a necessary part of the search for factors controlling NIS invasions.

NIS are particularly diverse and abundant in estuaries of the northeastern Pacific, including San Francisco Bay, California (Carlton and Geller, 1993, Cohen and Carlton 1995, 1997, Ruiz et al. 1997a, 1997b) and in Europe (Leppakoski, 1994, Leppakoski and Olenin, 1999, Eno, *et al.* 1997). The majority of these NIS have origins from western ocean coasts (Cohen and Carlton 1995, Leppakoski and Olenin, 1999) and progressively fewer NIS are known with increasing latitudes (Carlton 1979, Cohen *et al.* 1998, Mills *et al.* 2000). These geographical patterns do not appear to result entirely from the mechanisms of dispersal or patterns of endemic species diversity. Other processes controlling NIS distributions warrant consideration.

Potential climate effects on east and west and north and south patterns of NIS diversity among estuaries and coastal waters of the northern hemisphere are of paramount concern in any NIS risk analysis for Alaska. The cold temperate climate of Alaska is at the extreme northern range of many northeast Pacific intertidal species (O'Clair 1977, O'Clair and O'Claire 1998). Climate effects are therefore considered in this section. Salinity and temperature variations in estuaries are dominant processes of climate that limit NIS survival. Most estuarine species survive within narrow temperature and salinity ranges. Most chemical, biological, and hydrological processes that also limit the abundances and distributions of estuarine organisms are also controlled by, or closely correlated with, salinity and temperature (*e.g.*, Southward 1969, Green 1971, Ebbesmeyer et al. 1991, Cohen and Carlton 1995 1999, Chapman 1998, Thompson 1998). NIS distributions are therefore influenced by salinity and temperature within local estuaries. In turn, salinity and temperature are affected by climate (Ebbesmeyer et al. 1991, Cayan 1993). Precipitation and air temperature variations (Ebbesmeyer et al. 1991, Cayan 1993) can be interpreted to infer salinity and temperature variations in local estuaries even though direct, long-term measures of these parameters are lacking in most cases.

Amphipods recovered from 34 ballast water samples taken from tankers during 1998 were examined to determine whether amphipods are transported by ballast water traffic from west coast ports and harbors.

Methods

Rapid assessment survey

Prince William Sound, Seward and Homer, Alaska (60° 00' - 61° 00' N) survey results are compared to results of NIS surveys of the native, cryptogenic and introduced peracaridans from Puget Sound, Washington (47° 10' - 49° 00' N) and San Francisco Bay, California (37° 30' - 38° 10' N) to resolve how peracaridan NIS invasions are distributed over a broad range of latitudes.

Collections were made from three sites in Port Valdez in early spring of 1997, 46 sites throughout Prince William Sound in June 1998, and from 23 sites in Prince William Sound, Seward and Homer in 1999 (Ruiz and Hines 1997, Hines and Ruiz 1998) (Figure 9C4.1). Twenty six sites were surveyed in Puget Sound, Washington in September 1998 (Cohen *et al.* 1998). San Francisco Bay was surveyed in early fall, late spring or summer of 1993, 1994, 1996 and 1997 at 25 regular sites plus several irregular sites (Cohen 1998, Cohen and Carlton 1995, 1997, 1998). The three systems are excellent for comparison because they have all received and have been interconnected by significant aquaculture and shipping activities that are vectors of NIS dispersal in at least the last century.

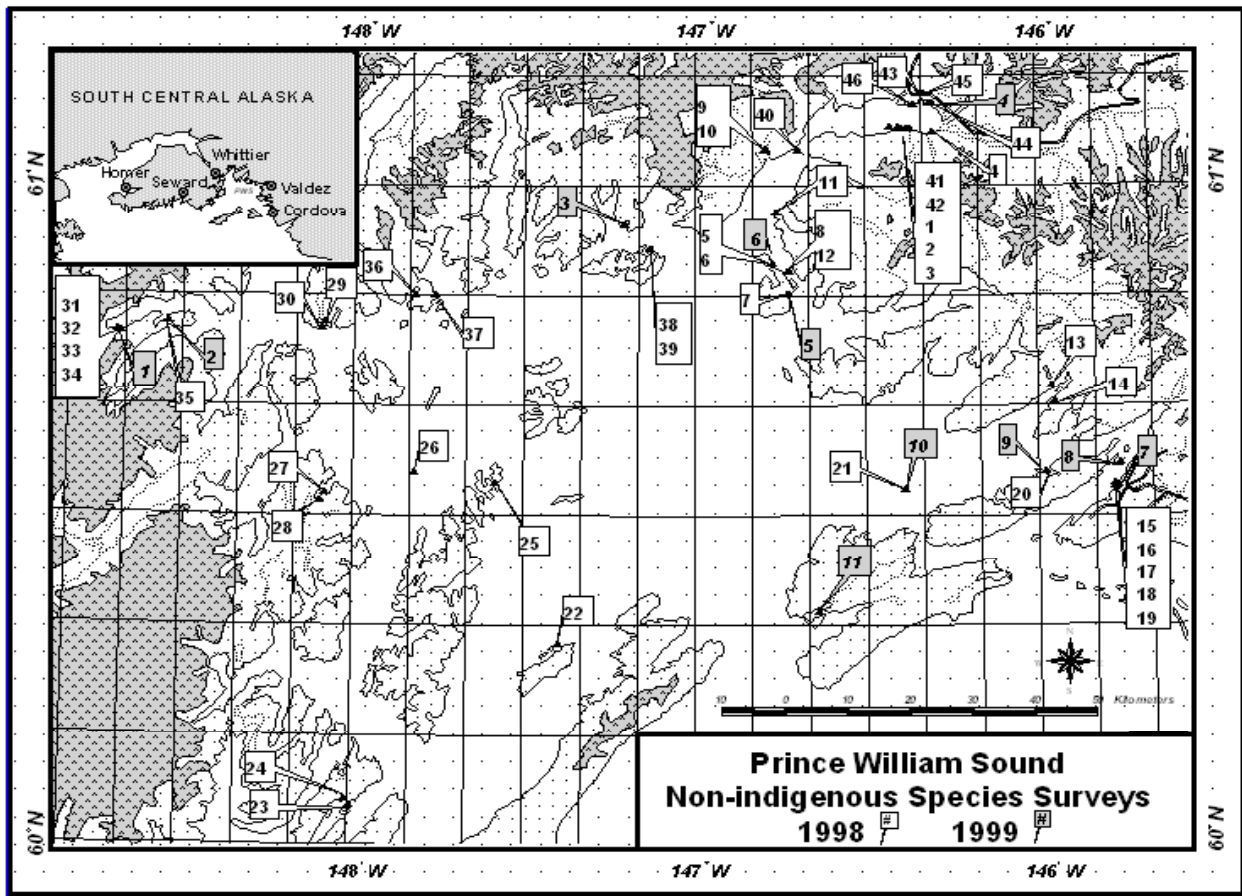


Figure 9C4.1. Prince William Sound, Alaska and south central Alaska rapid assessment sites with open boxes indicating all 46 sampling sites of 1998, inset indicating the five port areas sampled in 1999 and the shaded boxes indicating the eleven general sampling areas of the sound in 1999. (Latitudes longitudes and site descriptions are in appendix table 9C4.5).

Each area was surveyed by the author in the same fashion. Survey samples were collected by hand, scrapings, cores, or dredge as necessary to remove biological communities or substratum from floats, intertidal pilings rocks and intertidal or shallow subtidal mudflats accessible at each collection site. These samples were washed on an 0.5 mm mesh sieve directly or decanted onto an 0.5 mm mesh sieve and washed following vigorous sloshing in buckets of

seawater, to suspend organisms from the removed substratum. Harbor float, rock and piling substratums were emphasized in all three survey areas but other available habitats were sampled extensively as available. Organisms were picked directly from substratums during sample collection or from the sieves after washing or from voucher samples of substratums and examined under a stereomicroscope. All collected organisms were fixed in 10% formalin before transfer to 70% ETOH for long-term preservation. All specimens were identified to lowest possible taxonomic category.

Voucher specimens will be deposited in the Los Angeles County Museum, the California Academy of Sciences and the Smithsonian National Museum of Natural History. The precise locality records and notes for each collection site are available from the author. Temperature and salinity was measured at each collection site. Surface salinities ranged between 0 and 33 ‰ in all three survey areas. Surface water temperatures ranged between 8 and 20° C in Prince William Sound, between 10 and 21° C in Puget Sound and between 12 and 30° C in San Francisco Bay. San Francisco Bay is a well mixed estuary. Low surface salinities and clear stratification occur in both sounds in summer and were apparent during the surveys.

All species from the three surveys were collected and examined directly by the author and thus are assumed to be a more standardized sample than would be likely from comparisons of different surveys and sampling methods employed by different investigators. The indigenous origins of species are inferred from previously published records or herein using the criteria of Carlton (1979) and Chapman and Carlton (1991, 1994). The criteria used for cyptogenic species (species that are not clearly native or introduced) are adopted from Carlton (1996a). Only populations of species that have been moved by human activities to new locations, that are reproductive there, and that satisfy the criteria for nonindigenous species are considered here to be NIS.

Alaskan Climate and Peracaridan NIS Invasion Risks

Sources of NIS to Alaskan estuaries are available from a global population. The peracaridan Crustacea of the northern hemisphere considered here are as a sample of that population. Crustacea comprise approximately 25% of the 250 NIS reported from San Francisco Bay (Cohen and Carlton 1995, J. T. Carlton, personal communication), where they are the most diverse NIS taxon. The majority of these crustacean NIS are peracaridans. The Peracarida consist of relatively small, short-lived species that are primarily mysids, amphipods, isopods, tanaidaceans and cumaceans. The Peracarida are prominent in most North Pacific and North Atlantic marine and estuarine NIS communities (Bowman *et al.* 1981, Chapman 1988, 1999, Chapman and Carlton 1991, 1994, Mees and Fockedey 1993, Leppakoski 1994, Cohen and Carlton 1995, 1997, Eno *et al.* 1997, Toft *et al.* 1999). Both native and nonindigenous Peracarida are diverse, taxonomically well known, and ubiquitous in aquatic environments (*e.g.*, Barnard and Barnard 1983, Barnard and Karaman 1991, Chapman 1988, Cohen and Carlton 1995, Chapman 2000). Peracarida develop directly, without larval dispersal stages or unique life history traits that complicate identifications and interpretations of their geographical distributions. Peracaridans may thus provide clear indications of the patterns of diversity within and among broad geographical regions.

The species selected for the east to west geographical analysis of northern hemisphere peracaridan NIS are common or abundant where they occur and documented either in the literature or by personal observations. Species that are poorly documented, not examined directly, cryptogenic, or that are not introduced across the North Atlantic or North Pacific, were not included. For instance, the amphipod *Chelicorophium curvispinum* (Sars, 1895), which spread from the Black and Caspian Sea to northern Europe (Eno et. al. 1997), and the introduced mysid *Acanthomysis bowmani* Modlin and Orsi, 1997 in San Francisco Bay, which has unknown origins, and many northern NIS that are native to the southern hemisphere are not in the scope of this study and are therefore excluded from the analysis.

Long-term climate conditions in the northeast Pacific, including San Francisco Bay, Puget Sound and Prince William Sound are inferred from monthly average climate time series data for the Pacific Ocean and western Americas (Cayan et al. 1991). These data extend over approximately 100 years up to 1986. Global records of sea surface temperature and precipitation minus evaporation (<http://www.cdc.noaa.gov/> 1998) are used for comparisons of temperature among ocean regions. The term “western ocean” is used in reference to the Pacific Ocean bordering the east Asian coast and the Atlantic Ocean bordering the eastern North American coast. The term “eastern ocean” refers to the ocean areas bordering the west coasts of Europe and North Africa and the west coast of North America.

Amphipods in Ballast Water

Ballast water samples were collected in vertical plankton tows from “dedicated” ballast tanks, which are not contaminated by oil. Amphipods retained in the 0.25 mm mesh plankton nets preserved in 5% formalin, subsequently transferred to 70% ethanol for final sorting and identification. Samples were initially sorted under stereo microscopes at the Smithsonian Environmental Research Center or at the field office in Port Valdez and final amphipod identifications were performed at HMSC, Oregon State University.

The origins of the ballast water sampled (Table 9C4.3) were the Los Angeles-Long Beach area, the San Francisco Bay area, Puget Sound (Anacortes) and the open ocean. One ship, from the San Francisco Bay area, exchanged the ballast water at sea during transit. The potential for dispersal of nonindigenous species is assessed from the presence of nonindigenous species in samples.

Results

North - South Climate

The maximum, minimum, mean and range of monthly sea surface temperatures of the eastern Pacific vary by 5° C or less between 28° and 52° N (Figure 9C4.2). The 11 to 14° C maximum average monthly temperatures of Seward, Kodiak and Sitka, Alaska (between 58 and 60° N) overlap the Neah Bay, Washington maximum surface temperatures at 48° N and are similar to the 13° C average sea surface temperatures adjacent to San Francisco at 38° N (Figure 2). Nonindigenous species expected to reach south central Alaska might include those that can reproduce within Puget Sound in summer or in average San Francisco temperatures (Figure 9C4.2).

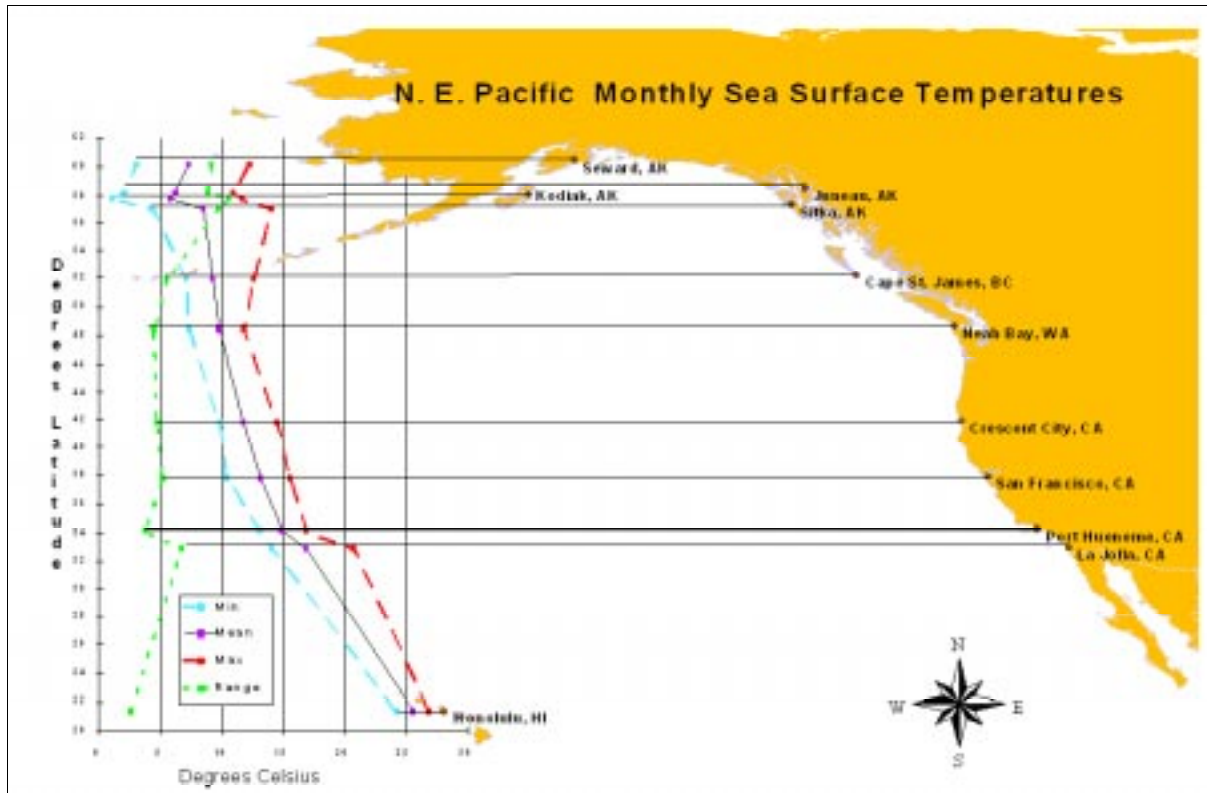


Figure 9C4.2. Sea surface temperature monthly average minimum, mean, maximum and range of northeast Pacific coastal waters estimate over an approximately 100 years up to 1986 (Cayan 1991).

North - South Biodiversity

Of the 106 peracaridan crustacean species identified from the surveys of Prince William Sound, Puget Sound and San Francisco Bay, 54 are native, 14 are cryptogenic and 38 are introduced (Table 9C4.1). Seven peracaridan crustaceans that prominent members of benthic or fouling communities that were recovered in the survey are cryptogenic (Table 9C4.1). They are the tanaidacean *Leptochelia dubia* (Kroyer, 1842) a cosmopolitan species (Miller, 1975); the cumacean *Cumella vulgaris* Hart, 1930 which occurs in Asia (Lomakina 1958) as well as the eastern Pacific; the amphipod *Monocorophium carlottensis* Bousfield and Hoover, 1997 is not clearly distinguished from the nonindigenous amphipods *Monocorophium acherusicum* and *Monocorophium insidiosum* (Ruiz and Hines 1997); the amphipod *Hyale plumulosa* (Stimpson, 1857) is reported also from the western Atlantic (Bousfield 1973); the amphipod *Jassa staudei* Conlan 1990 is extremely similar to the cosmopolitan *Jassa marmorata* Holmes, 1903; the amphipod *Pontogeneia rostrata* Gurjanova, 1938 is reported from the eastern and western Pacific (Gurjanova 1938, 1951, Barnard 1962, 1964); the caprellid *Caprella depranochir* Mayer, 1880 is reported from the eastern and western Pacific (Arimoto 1976, Kozloff and Price 1997).

Table 9C4.1. The 106 peracaridan crustaceans identified as nonindigenous, cryptogenic or native, and the records per species collected from San Francisco Bay, California, (w/o “*”), south central Alaska and Prince William Sound (with “*”), or Puget Sound, Washington (underlined). *Gnorimosphaeroma lutea* was collected from San Francisco Bay and Prince William Sound only. No species were collected only in Puget Sound.

Nonindigenous	Records	Cryptogenic	Records	Native	Records
Mysidacea		Tanaidacea		Mysidacea	
<i>Accanthomysis aspera</i>	1	<u><i>eptochelia dubia</i></u>	3	<i>Mysis littoralis</i> *	1
Tanaidacea		Cumacea		Isopoda	
<u><i>Tanais stanfordi</i></u>	2	<u><i>Cumella vulgaris</i></u>	3	<u><i>Dynamenella glabra</i></u> *	2
Isopoda		Gammaridea		<u><i>Gnorimosphaeroma lutea</i></u>	2
<i>Asellus sp.</i>	1	<u><i>Ampithoe lacertosa</i></u>	3	<i>Gnorimosphaeroma oregonense</i>	3
<i>Dynoides dentisinus</i>	1	<i>Dulichia sp.</i>	1	<u><i>Ianiropsis kincaidi</i></u> *	2
<i>Euylna arcuata</i>	1	<u><i>Hyale plumulosa</i></u>	3	<u><i>Idotea montereyensis</i></u>	3
<i>Ianiropsis serricadus</i>	1	<u><i>Ischyrocerus sp.</i></u>	2	<i>Idotea obscura</i> *	1
<i>Limnoria quadripunctata</i>	1	<u><i>Jassa staudei</i></u>	3	<u><i>Idotea resecata</i></u>	2
<u><i>Limnoria tripunctata</i></u>	2	<u><i>Monocorophium carlottensis</i></u> *	2	<u><i>Idotea wosnenskii</i></u>	3
<i>Munna ubiquita</i>	1	<u><i>Pontogeneia rostrata</i></u>	3	<i>Ligia pallasi</i> *	1
<i>Paranthura sp.</i>	1	Caprellidea		<u><i>Limnoria lignorum</i></u>	2
<i>Sphaeroma quoyanum</i>	1	<u><i>Caprella depranochir</i></u> *	2	Cumacea	
<i>Synidotea laevidorsalis</i>	1	<u><i>Caprella laeviuscula</i></u>	3	<i>Diastylis alaskensis</i> *	1
Cumacea		<i>Caprella penantus</i>	1	<i>Diastylis sp.</i> *	1
<u><i>Nippoleucon hinumensis</i></u>	2	<u><i>Caprella verrucosa</i></u>	2	<i>Lamprops beringi</i> *	1
Gammaridea		<i>Tritella sp.</i>	1	<u><i>Lamprops quadriplacata</i></u> *	2
<i>Ampelisca abdita</i>	1			Gammaridea	
<u><i>Ampithoe valida</i></u>	2			<u><i>Allorchestes angusta</i></u>	3
<i>Crangonyx sp.</i>	1			<u><i>Americorophium brevis</i></u> *	2
<u><i>Eochelidium sp.</i></u>	2			<u><i>Americorophium salmonis</i></u> *	2
<i>Gammarus daiberi</i>	1			<u><i>Americorophium spinicorne</i></u>	2
<u><i>Grandidierella japonica</i></u>	2			<u><i>Ampithoe dalli</i></u> *	2
<i>Hyalella azteca</i>	1			<i>Ampithoe kussakini</i> *	1
<u><i>Jassa marmorata</i></u>	2			<i>Ampithoe sectimanus</i> *	1
<u><i>Laticorophium baconi</i></u>	2			<u><i>Ampithoe simulans</i></u> *	2
<i>Leucothoe alata</i>	1			<u><i>Anisogammarus pugettensis</i></u>	3
<u><i>Melita nitida</i></u>	2			<u><i>Aoroides columbiae</i></u>	3
<i>Melita sp.</i>	1			<u><i>Aoroides intermedius</i></u> *	2
<u><i>Monocorophium</i></u>	2			<u><i>Calliopius carinatus</i></u> *	2
<u><i>acherusicum</i></u>					
<u><i>Monocorophium insidiosum</i></u>	2			<u><i>Calliopius pacificus</i></u> *	2
<i>Monocorophium oaklandense</i>	1			<u><i>Eogammarus confervicolus</i></u>	3
<i>Monocorophium uenoi</i>	1				
<i>Trasorchestia enigmatica</i>	1			<i>Eogammarus oclairi</i> *	1
<i>Paradexamine sp.</i>	1			<i>Gammaridae n. gen. n. sp.</i> *	1
<i>Parapleustes derzhavini</i>	1			<u><i>Gnathopleustes pugettensis</i></u>	2
<u><i>Senothoe valida</i></u>	2			<u><i>Hyale frequens</i></u>	3
<i>Sinocorophium heteroceratum</i>	1			<u><i>Lagunogammarus setosus</i></u> *	2
Caprellidea				<i>Locustogammarus locustoides</i> *	1
<u><i>Caprella acanthogaster</i></u>	2				
<i>Caprella bidentata</i>	1			<u><i>Megamoera subtener</i></u> *	2
<u><i>Caprella californica</i></u>	2			<i>Microdeutopus schmitti</i>	1
<u><i>Caprella equilibra</i></u>	2			<i>Najna n. sp.</i> *	1
				<u><i>Paracalliopiella pratti</i></u> *	2
				<u><i>Parallorchestes ochotensis</i></u>	3

Table 9C4.1. Continued

<i>Paramoera bousfieldi</i> *	2
<i>Paramoera mohri</i> *	1
<i>Parampithoe humeralis</i> *	2
<i>Parampithoe mea</i> *	1
<i>Photis brevis</i>	2
<i>Pontogeneia inermis</i>	3
<i>Pontogeneia ivanovi</i> *	1
<i>Pontoporeia femorata</i> *	2
<i>Spinulogammarus subcarinatus</i> *	1
<i>Trasorchestia traskiana</i>	3
Caprellidea	
<i>Caprella alaskana</i> *	1
<i>Caprella gracilior</i> *	1
<i>Caprella irregularis</i> *	2
<i>Metacaprella kenerlyi</i> *	2

Total Species	38	14	54
Records/Species	1.4	2.1	1.8

The diversity of species collected is nearly nearly constant among sites (66 to 60 and 59, respectively, between San Francisco, Puget Sound and Prince William Sound). Of the 54 native species collected in Alaska, 52 (96%) were collected also in San Francisco Bay or Puget Sound (Table 9C4.1). The common pool of native species and the similar species diversities collected among the three areas both indicate that the habitat selection, collection and sample processing methods of the rapid assessment surveys were consistent among the three areas. Little variation in NIS diversity among these three sample sets was therefore likely to result from sample biases.

From San Francisco Bay north to Puget Sound and Prince William Sound, introduced peracaridan species declined from 38 to 15 to 0 (Figure 9C4.3, $X^2 > 27.01$; $p < 0.0001$; $df = 2$), while the frequencies of cryptogenic peracaridan species were nearly constant at 11, 10 and 8, respectively ($X^2 = 2.0$; $p > 0.73$; $df = 2$). In contrast, the frequencies of native species increased to the north from 17 to 35 and 52 (Figure 9C4.3, $X^2 > 27.01$; $p < 0.0001$; $df = 2$). All peracaridan NIS and all but two of the cryptogenic peracaridan species at any site also occurred in San Francisco Bay while only 17 of the 54 native species were recovered from San Francisco Bay (Table 9C4.1, Figure 9C4.3). The peracaridan NIS that managed to invade northeast Pacific estuaries thus have adaptations to lower latitude climates than do the native species. The affinities of peracaridan NIS for low latitude climates closely corresponds to a pattern that would be expected if the peracaridan NIS are poorly adapted to cold water conditions or other factors of climate that vary with latitude.

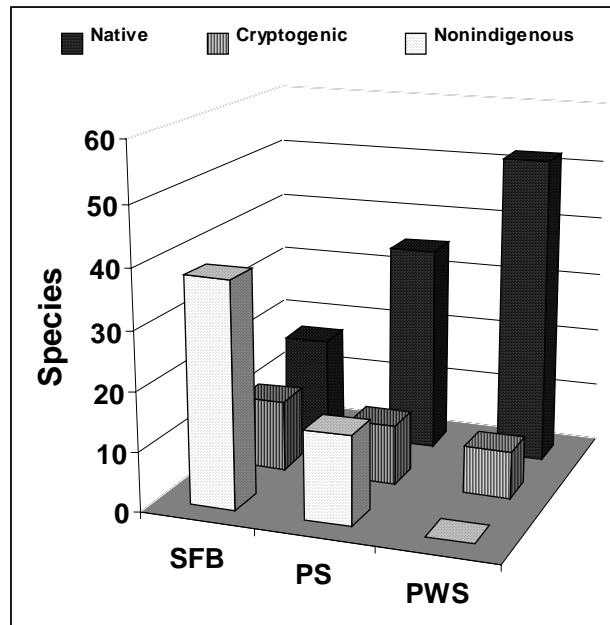


Figure 9C4.3. Native, cryptogenic, nonindigenous and total species in samples from San Francisco Bay, California, Puget Sound, Washington and Prince William Sound, Alaska (SFB, PS and PWS, respectively).

Some NIS may be among the 8 cryptogenic peracaridan species of Prince William Sound (Figure 9C4.3). Six of these cryptogenic Alaskan peracaridan species have broad thermal tolerance ranges and occur also in Puget Sound and San Francisco Bay (Table 9C4.1). The nearly complete faunal peracaridan overlap between Alaska and the two more southern sites indicate that the low diversity of Alaskan NIS peracaridans are not likely to result from unique types of NIS peracaridans that were not collected in the survey. The nearly uniform pool of native peracaridan species and uniform pool of NIS peracaridans among the areas require few qualifications or assumptions to arrive at conclusions of the patterns of diversity. The possibility of overlooking populations of nonindigenous peracaridan crustaceans in Alaska that occur at similar diversities and abundances as in Puget sound or San Francisco Bay, by these rapid assessment methods, is remote. The presence of peracaridan NIS that are not among the cryptogenic species of peracaridans in Alaskan estuaries and marine waters is not significantly different from zero.

These results are not surprising. The extreme climate of Alaska was previously assumed to limit the survival of nearly all NIS peracaridans. However, these data include only a single coast and three major areas of reference. NIS peracaridan diversity was therefore compared between other geographical regions with climates that vary similarly to the variation that occurs between San Francisco and south central Alaska as a further test of the climate pattern.

East -West Climate

Sea surface temperatures are relatively constant between latitudes of 25° and 50° N in eastern oceans compared to western ocean areas (Figures 9C4.4 and 9C4.5). Eastern ocean species from 32° to 50° N evolved in temperature ranges that span only latitudes 40 to 42° N in

western oceans (Figure 9C4.6). Eastern ocean species thus have not evolved in conditions that would create broad temperature tolerance ranges. In contrast, most western ocean organisms survive temperature ranges exceeding the total temperature range of broad eastern ocean areas. Eastern oceans below 50° N, are thus broad thermal targets for western ocean species over space and time while western ocean coasts are narrow thermal targets for eastern ocean species.

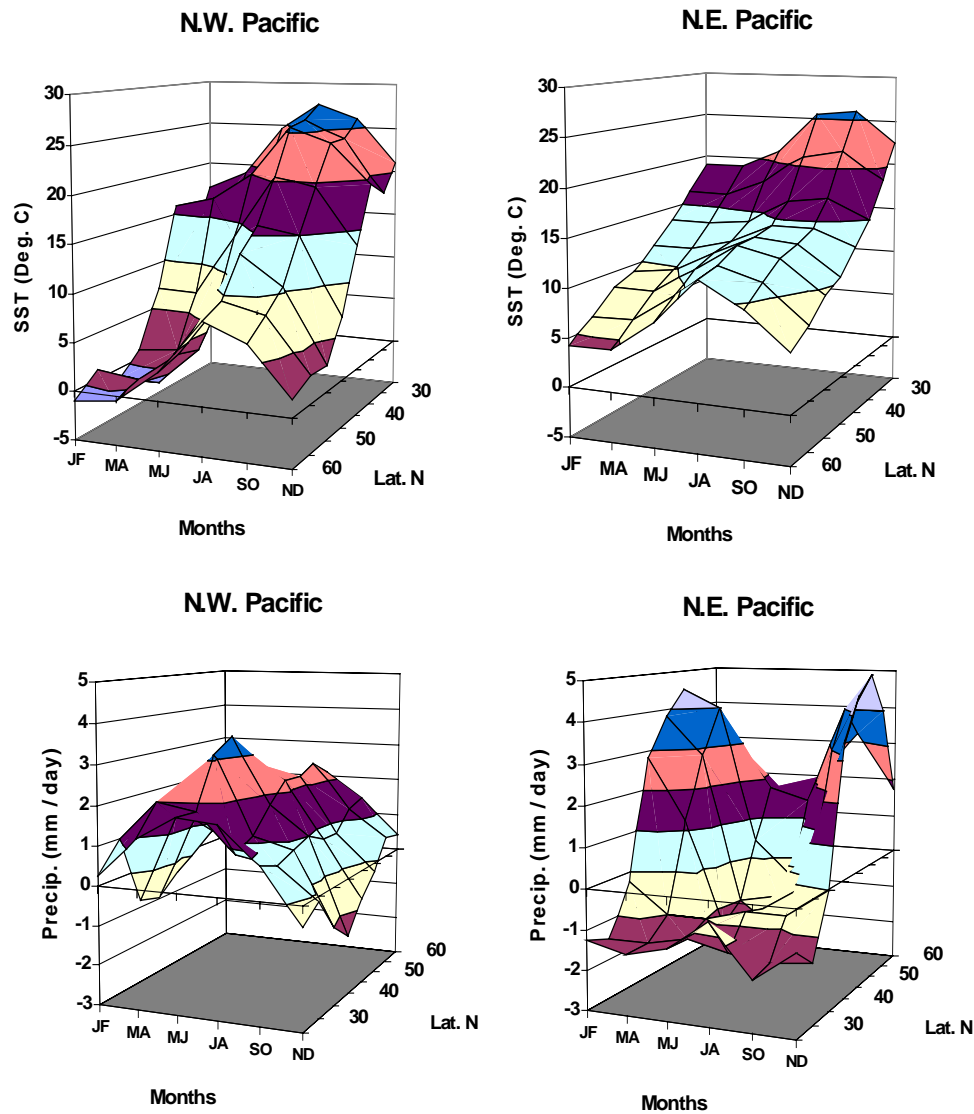


Figure 9C4.4. Northwest and northeast Pacific sea surface temperature in degrees Celsius and bimonthly precipitation minus evaporation in $\text{mm}^{-\text{d}}$ at ten degree latitude intervals for the bimonthly periods of Jan-Feb, Mar-Apr, May-Jun, Jul-Aug, Sep-Oct and Nov-Dec. (Note: axes of latitude are reversed between graphs of temperature and

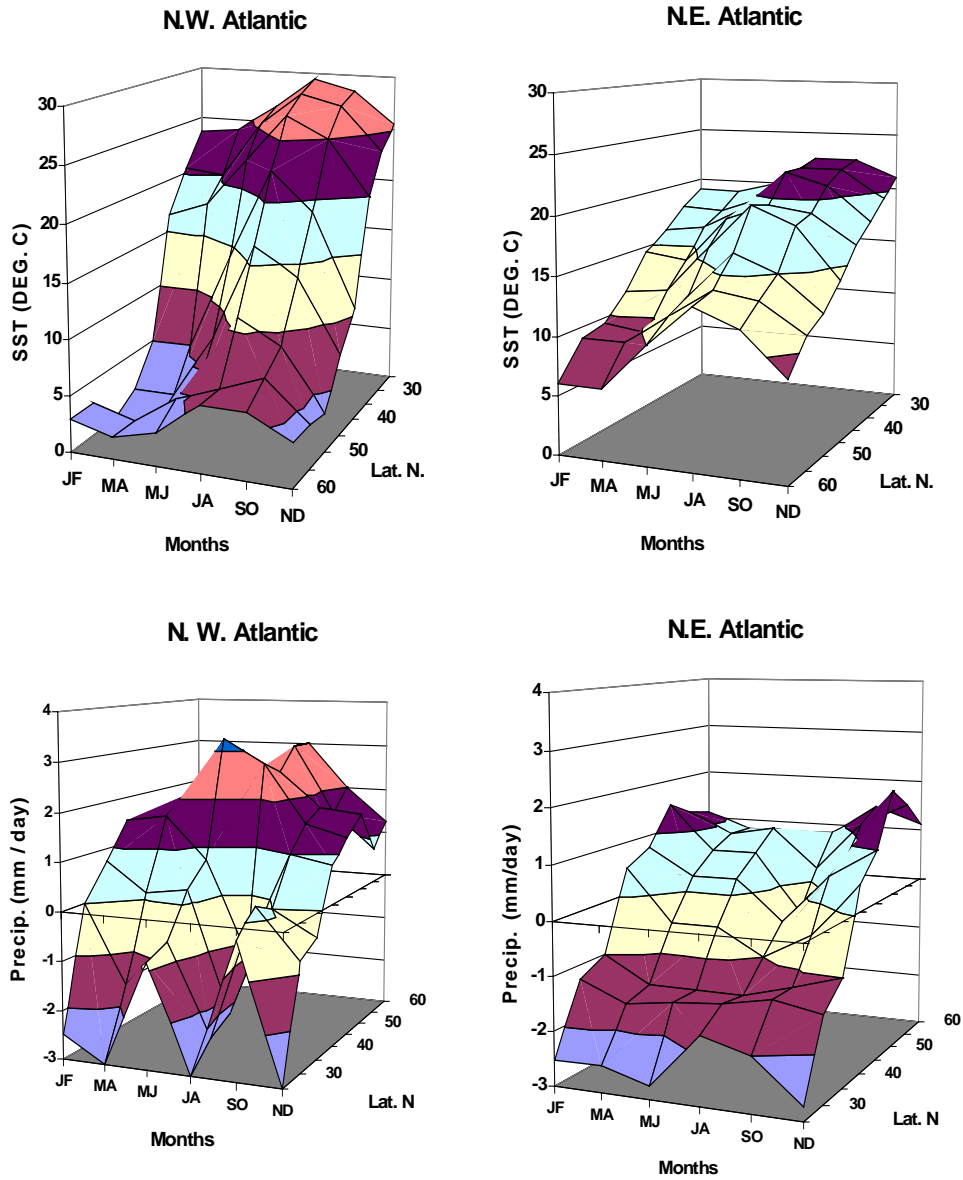


Figure 9C4.5. Northwest and northeast Atlantic sea surface temperature in degrees Celsius and bimonthly precipitation minus evaporation in $\text{mm}^{-\text{d}}$ at ten degree latitude intervals for the bimonthly periods of Jan-Feb, Mar-Apr, May-Jun, Jul-Aug, Sep-Oct and Nov-Dec. (Note: axes of latitude are reversed between graphs of temperature and precipitation.)

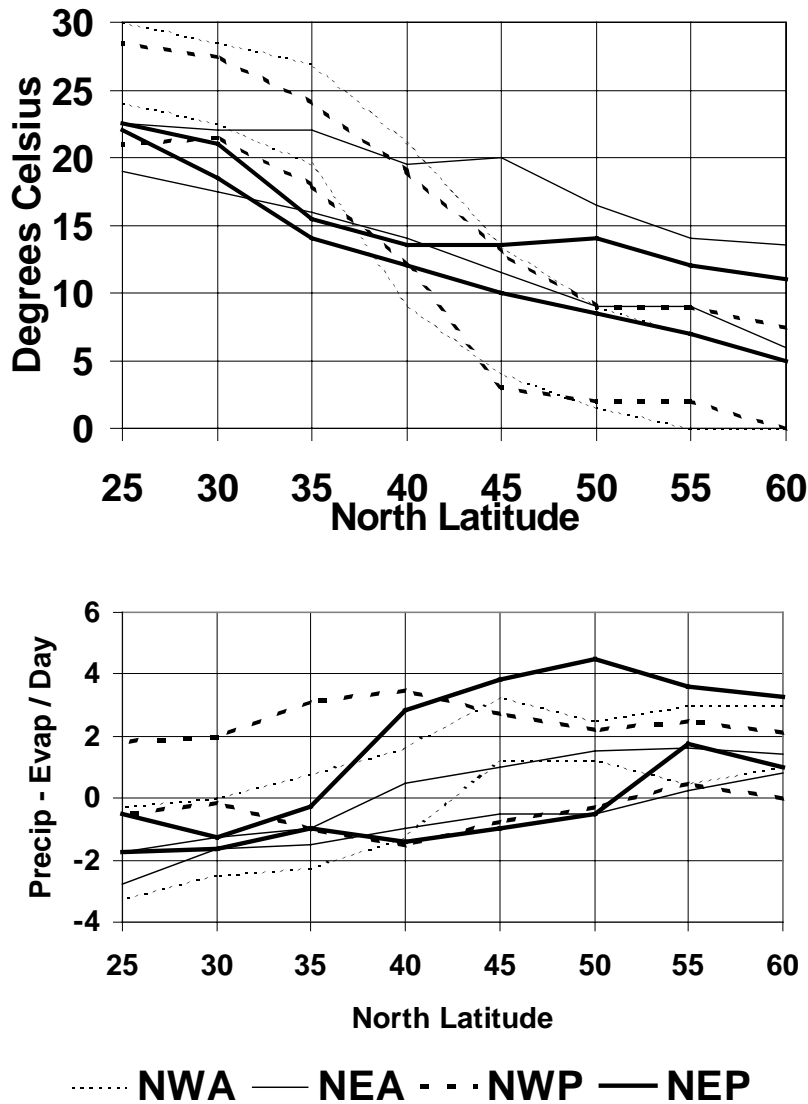


Figure 9C4.6. Maximum and minimum monthly sea surface temperature in degrees Celsius (A) and monthly precipitation minus evaporation in mm d⁻¹ (B) at ten degree latitude intervals for the northwest (dashed lines) and northeast (solid lines) Atlantic (thin lines) and Pacific (thick lines). Northeast Pacific, northwest Pacific, northeast Atlantic and northwest Atlantic are NEP, NWP, NEA and NWA, respectively.

Precipitation, and thus salinity in estuaries, also vary from east to west in patterns that resemble the south to north pattern from San Francisco to Alaska. The broadest ranges of precipitation occur in the eastern Pacific north of 35° N. Lat. (Figure 9C4.4). The narrowest ranges of precipitation and negative net precipitation (desert conditions) occur in the eastern Pacific and Atlantic south of 35° N. Lat. (Figure 9C4.4). Desert conditions do not occur at low latitudes in the northwest Pacific and occur in the northwest Atlantic only below 30° N (Figure

9C4.4). The latitudinal range and areal extent of low salinity estuaries is therefore less in eastern oceans than in western oceans and the climates are more uniform.

The seasonal patterns of precipitation (Figures 9C4.4 and 9C4.5) also differ consistently between eastern and western oceans. More precipitation occurs in western oceans during summer when temperatures are maximum while most precipitation occurs in eastern oceans in winter when temperature are low (Figures 9C4.4 and 9C4.5). Where snow-melt is not important, and in the absence of major water impoundments, the salinity-temperature patterns of eastern and western ocean estuaries are out of synchrony. In high latitude regions, such as Alaska, runoff varies most with snow-melt and salinity is lower in warm seasons in correspondence with western ocean climates.

East and West Biodiversity

Peracaridan NIS diversity varied among the four northern hemisphere ocean coasts ($X^2 = 17.27$, $p = 0.001$ $df = 3$), with five times as many introductions to eastern ocean coasts (Table 9C4.2; $X^2 = 16.05$, $p = 0.001$ $df = 1$). Except for the gammaridean amphipods *Orchestia gammarella* (Pallas, 1766) and *Corophium volutator* (Pallas, 1766) in the tidal mudflats and marshes of the Bay of Fundy, peracaridan NIS abundance and diversity in western Atlantic estuaries appeared to be low. Similarly, of the 28 peracaridan species included in the east to west analysis, only 2 - 3 NIS were in the northwest Pacific, compared to 20-23 in the northeastern Pacific and 10-12 in the northeast Atlantic (Table 9C4.2). None of the common northeast Pacific peracaridans were introduced to other areas of the world. Only 2 of the northeast Atlantic species were clearly introduced to other regions compared to 13 from the northwest Pacific and 14 from the northwest Atlantic (Table 9C4.2). Remarkably, 5 - 9 of the 28 NIS (Table 9C4.2) have been reported on two coasts and 4 of these species have been discovered on 3 coasts.

Climate and NIS Diversity

The ranks of climates from least to most similar based on overall temperature variation and seasonal precipitation (Figures 9C4.2, 9C4.3 and 9C4.4) were, northeast Pacific, northeast Atlantic, northwest Pacific and northwest Atlantic (NEP, NEA, NWP and NWA, respectively). The ranks of NIS invaders of these regions (Imports, Table 1) were from highest to lowest: NEP, NEA, NWP and NWA. The ranks of native species that have been introduced to other regions (Exports, Table 1) were from lowest to highest: NEP, NEA, and NWP and NWA. The east and west variations in NIS imports and exports were thus correlated with climate variation (Kendall coefficient of concordance $W = 1.0$; $X^2 = 8.2$; $p < 0.02$; $df = 2$) (Siegal 1956) in a similar pattern to the south to north pattern of NIS between San Francisco Bay and Prince William Sound.

Table 9C4.2. The east and west destinations and sources of common introduced peracaridan crustaceans of the Northwest Pacific Northeast Pacific, Northwest Atlantic and Northeast Atlantic (NWP, NEP, NWA and NEA, respectively), their native, introduced, or probable introduced status (N, I, and I?, respectively) and the numbered reference sources.

Common Introduced Nonindigenous Estuarine Peracaridan Crustaceans of the Northern Hemisphere					
	NWP	NEP	NWA	NEA	Sources
Mysidacea					
<i>Acanthomysis aspera</i>	N	I			1,2
Cumacea					
<i>Nippoleucon hinumensis</i>	N	I			1,3
Isopoda					
<i>Asellus communis</i>		I?	N	I	4
<i>Caecidotea racovitzai</i>		I	N		7
<i>Dynoides dentisinus</i>	N	I			1
<i>Ianiropsis serricatus</i>	N	I			1,8
<i>Paranthura sp.</i>	N	I			1
<i>Synidotea laevidorsalis</i>	N	I	I	I	1,5
Amphipoda					
<i>Ampelisca abdita</i>		I	N		1,6,10
<i>Ampithoe valida</i>		I	N		1,9,10
<i>Apocorophium lacustre</i>			N	I	13,14
<i>Caprella acanthogaster</i>	N	I		I	1,10,11
<i>Corophium sp.</i>	N			I?	15,16
<i>Corophium volutator</i>			I	N	13,14,17
<i>Crangonyx floridanus</i>		I	N		7
<i>Crangonyx pseudogracilis</i>			N	I	18
<i>Gammarus daiberi</i>		I	N		1,7
<i>Gammarus tigrinus</i>			N	I	13,14,18,19
<i>Grandidierella japonica</i>	N	I		I	10,20,21
<i>Jassa marmorata</i>	I	I	N	I	10,22,23
<i>Leucothoe alata</i>	N	I			1,24
<i>Melita nitida</i>	I?	I	N		1,6,10
<i>Microdeutopus gryllotalpa</i>		I	N	I	13,25
<i>Monocorophium uenoi</i>	N	I			9,10
<i>Monocorophium acherusicum</i>	I	I	N	I	1,9,10
<i>Monocorophium insidiosum</i>	I	I	N	I	1,9,10
<i>Orchestia gammarella</i>			I?	N	13,14,19
<i>Parapleustes derzhavini</i>	N	I			1,6,10
<i>Sinocorophium heteroceratum</i>	N	I			1,12
Total Natives (Exports)	13	0	14	2	
Total NIS (Imports)	1 - 3	21 - 23	2 - 3	10 - 12	

N = native; I = introduced; ? = distribution not completely resolved but probable

1) Cohen and Carlton 1995; 2) Modlin and Orsi 1997; 3) Watling 1991; 4) Williams 1972; 5) Chapman and Carlton 1991, 1994; 6) Chapman 1988; 7) Toft et al. 1999; 8) Kussakin 1988; 9) Barnard 1975; 10) Carlton 1979; 11) Platvoet et al. 1995; 10) Carlton 1979; 12) Chapman and Cole In Prep.; 13) Bousfield 1973; 14) Lincoln 1979; 15) Hirayama 1984, 1986; 16) Janta 1995; 17) Chapman and Smith In prep.; 18) Costello 1993; 19) Watling 1979; 20) Chapman and Dorman 1975; 21) Smith et al. 1999; 22) Conlan 1990; 23) Mills et al. 1999; 24) Nagata 1965a-d; 25) Chapman and Miller In Prep.

BW Source	Temperature	Salinity	Ship ID #	Sample Date	Vessel	Ampelisca abdita	Argissa hamatipes	Corophium acherusicum	Corophium heteroceratum	Cyphocharis challengerii	Eogammarus confervicous	Gammarus daiberi	Gibberosus longimerus	Grandidierella japonica	Hartmanodes harmanni	Hyperia cf medusarum	Melphisana bola	Pontogeneia rostrata	Tiron sp.	Westwoodilla caecula
Port Valdez	6	34	TN-6-1	3/12/98	Alyeska Benth-4					2										
Port Valdez	7	30	CN-4-2	3/11/99	Dock side															1
Benicia/Ocean	19	33	130 1-1	8/27/98	S/R Northslope											12				
Anacortes	6	29	037-1-1	1/23/98	SR Benicia											2				
Anacortes	7	30	177-1-2	12/22/98	S/R Baytown											1				
Anacortes	8	32	82-1-1	5/10/98	S/R Benicia											12				
Anacortes	8	32	82-1-1	5/10/98	S/R Benicia														1	
Anacortes	9	32	086-1-1	5/21/98	Sea River											5				
Anacortes	12	30	103-1-2	6/25/98	Sea Rr, San Francisco											3				
Anacortes	13	30	116-1-2	7/25/98	S/R/ Baton Rouge											1				
Anacortes	13	31	137-1-2	8/18/98	???											2				
Anacortes	14	30	1331-2	9/10/98	Baytown											5				
Martinez	7	0	073-1-1	4/15/98	Sea River							3								
Benicia	9	4	083-1-1	5/16/98	Sea River, Baton Rouge							1								
Benicia	9	5	077-1-1	4/26/98	Sea River/North Slope					1										
Benicia	9	5	75-1-1	4/19/98	Sea River, Long Beach							5								
SF Bay	10	23	081-1-1	5/7/98	Sea River							4								
Benicia	13	2	101-1-2	6/22/98	S/R Benicia							3								
Benicia	13	2	097-1-1	6/11/98	S/R Long Beach							1								
Benicia	13	3	0881-1	5/23/98	???						3									
Richmond	13	20	104-1-2	7/1/98	Denali	1														
Richmond	15	22	113-1-2	7/17/98	Denali	1	1													
Richomod	16	24	126 1-2	8/19/98	BT Alaska						1		1							
Santa Monica	7	25	070-1-2	8/4/98	Prince William Sound	1														
El Segundo	8	35	170-1-1	12/10/98	Columbia	1					3									
Long Beach	8	35	176-1-2	12/19/98	Arco Spirit											2				
Long Beach	9	35	173-1-1	12/12/98	Arco Independence							1			1					
Long Beach	10	35	169-1-2	12/1/98	Arco Spirit			1												
Long Beach	10	35	076-1-2	4/22/98	Arco Independence	1						1	5	5						
Long Beach	10	35	169-1-2	12/1/98	Arco Spirit										3					1
Long Beach	10	35	169-1-2	12/1/98	Arco Spirit							3								
Long Beach	10	35	164-1-2	11/24/98	Arco Independence											2				
Long Beach	11	32	026-1-1	12/28/97	Arco Independence											1				
Long Beach	14	35	162-1-1	11/15/98	Arco Spirit											2	1			
Long Beach	14	35	148-1-1	10/12/98	Arco Spirit											3				
Long Beach	15	35	102-1-1	6/24/98	Arco Indio (L B)	1									12	2				

Table 9C4.3. Ballast and Port Valdez amphipods zooplankton samples subdivided into major source areas (Port Valdez, Benicia water exchanged at sea, San Francisco Bay area and southern California, respectively).

Amphipods in Ballast Water

The 125 specimens recovered include one hyperiid species and fourteen species and ten families of gammaridean amphipods. Five of the gammaridean amphipods are NIS in the northeast Pacific and were present in ballast tanks discharged into waters of Port Valdez. These preliminary data indicate that ballast water traffic is a potential mechanism for transporting amphipods among harbors and coastal U. S. waters. The amphipod diversity in these samples (Table 9C4.4) is high given the small number of specimens involved. Except for the Ocean exchanged water and the water from Anacortes, Puget Sound, the heterogeneity among zooplankton sources is almost complete with a significant difference among the four species represented by more than 8 specimens (O^2 ; $p < 0.001$, $df = 12$). Only *Ampelisca abdita* and *Gammarus daiberi* occurred in more than one zooplankton source. Descriptions of the amphipods in these records are given in Appendix Table 94C. 8. The occurrence of amphipod species as a function of temperature and salinity of ballast water is shown in Figures 9C4.7 and 9C4.8, respectively.

	Water Source					Total
	Port	Open	Puget	San Francisco	Southern	
Temperature	Valdez	Ocean	Sound	Bay	California	
Salinity	6.5	19.0	10.0	11.5	10.5	
Samples	32.0	33.0	30.7	10.0	34.0	
	2	1	9	11	13	36
Species	Origin					
<i>Pontogeneia rostrata</i>	C		1			1
<i>Ampelisca abdita</i>	I			2	2	4
<i>Monocorophium acherusicum</i>	I			1		1
<i>Sinocorophium heteroceratum</i>	I				1	1
<i>Gammarus daiberi</i>	I			17	3	20
<i>Grandidierella japonica</i>	I			1		1
<i>Argissa hamatipes</i>	N				2	2
<i>Cyphocharis challengeri</i>	N	2				2
<i>Eogammarus confervicous</i>	N			5		5
<i>Gibberosus longimerus</i>	N				5	5
<i>Hartimanodes hartmannae</i>	N				31	31
<i>Hyperia cf. medusarum</i>	N	12	31			43
<i>Melphisana bola</i>	N				8	8
<i>Tiron sp.</i>	N				1	1
<i>Westwoodilla caecula</i>	N	1				1
Cryptogenic (C)	0	0	1	0	0	1
Introduced (I)	0	0	0	21	6	27
Native (N)	3	12	31	5	47	98
Total	3	12	32	26	53	126

Table 9C4.4. The average salinities, temperatures, subtotals, cryptogenic, introduced and native origins and total numbers of amphipod Crustacea collected in Port Valdez waters and from dedicated ballast tanks containing water exchanged at sea, or entrained from Puget Sound, San Francisco Bay or southern California.

Discussion

Most estuarine peracaridan NIS of the northeast Pacific are from the western sides of the Pacific or the Atlantic oceans. Peracaridan crustacean NIS diversity coincided with particular climates between 25 and 60° N. Lat. Annual sea surface temperatures at latitudes below 50° N vary less along northeast Pacific and Atlantic coasts than along western ocean coasts and, also in contrast to western ocean coasts, low salinity conditions occur in winter months rather than the summer months.

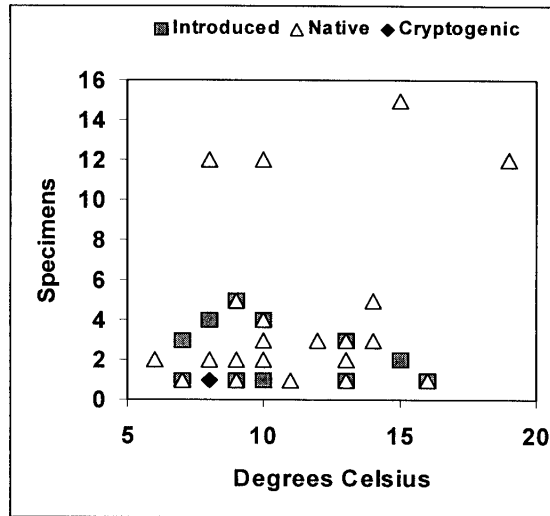


Figure 9C4.7. Native, introduced and cryptogenic amphipod numbers with temperature from 34 ballast water samples.

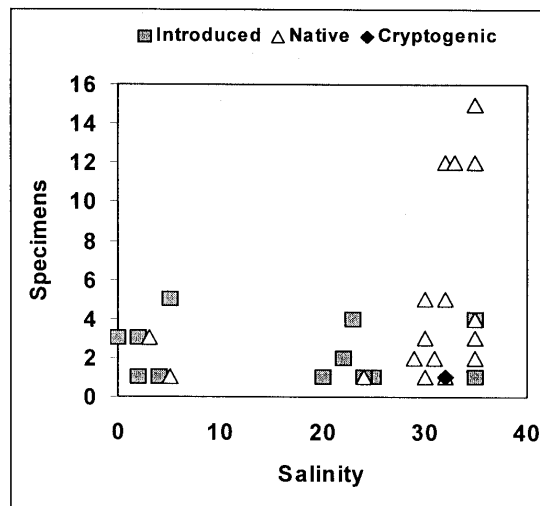


Figure 9C4.8. Native, introduced and cryptogenic amphipod numbers with salinity from 34 ballast water samples.

The great diversity of invading species in northeast Pacific estuaries may thus result, in part, from the great diversity of climates that invading species are adapted to relative to the narrow range of climates in the region. The low diversity of native northeast Pacific species that invade other areas may also result, in part, from the relatively broad range of climate variations they must endure to survive elsewhere. The decline of northeast Pacific NIS diversity from south to north coincides with fewer introductions occurring where greater annual variations in temperature occur and where low salinity conditions occur during warm water periods.

All of the peracaridan NIS known from Puget Sound occurred also in San Francisco Bay. The absence of cold water NIS in Southern Alaska is consistent with a pattern of introductions

occurring less in continental climates of high temperature variations and low summer salinities. The overall pattern of NIS peracaridan diversity in the northern hemisphere strongly suggests that northeast Pacific estuarine peracaridan NIS of San Francisco Bay and north are predominantly from lower latitudes. Few of the presently known recognized northeast Pacific NIS peracaridans are thus likely to become established in southern Alaskan waters, even though Alaskan weather variations resemble western ocean climates from where most NIS originate.

Aquatic species with nearly any life history and from nearly any taxon can be introduced (e.g. Carlton 1985, Cohen and Carlton 1995, Eno et al. 1997, Smith *et al.* 1999, Hewitt et al. 1999). The many vectors, directions, distributions, routes of introduction (e.g., Carlton 1979, 1985, 1987, 1999, Carlton and Geller 1993, Ruiz *et al.* 1997) and taxa available for introductions over the last 500 years (e.g. Carlton 1992, Carlton and Hodder 1995, Ruiz et al. 1997) have moved broad diversities of species to many suitable and unsuitable areas. The present distributions of NIS are a mosaic of surviving populations composed of a broad diversity of taxa and life histories. These surviving nonindigenous populations are surrounded by unsuitable areas in which they were also introduced but failed to survive. The patterns of transport mechanisms superimposed on this mosaic reveal where introductions fail. Resolution of this global pattern can reveal sources, destinations, targets and vectors of NIS and which ecosystems are most vulnerable.

The probability of particular species introductions from one region to another cannot be determined from these data. NIS invasions in northern hemisphere estuaries, even confined to peracaridan crustaceans, are more complex than Tables 9C4.1 and 9C4.2 indicate. Additionally many evolutionary and ecological processes that are likely to contribute to the patterns of NIS invasions are not addressed. Western ocean estuaries may be older, with more diverse biotas and could be less intensely altered by human activities, for instance, than eastern ocean estuaries. When and how climates control NIS distributions are complicated by other processes including human and natural disturbances, and the timing, geography and magnitude of transport vectors. Also, the complexity of climate variations are drastically simplified in Figure 9C4.2, and Figures 9C4.4 - 9C4.6 on the assumption that large populations distributed over broad geographic areas are more likely to reflect average conditions over extended periods. However, other time intervals for integration could be better than the one and two month averages selected here for climate analyses. These simplifications may reduce the fit between biogeographical boundaries and climate and thus obscure interactions between NIS distributions and climate.

These correlations between west ocean to east ocean NIS peracaridan invasions and climate nevertheless deserve close inspection. Source and destination climates for peracaridan NIS may be easier to identify than particular species that are likely to be introduced by particular dispersal vectors. Moreover, peracaridans appear to be a sufficient taxon to sample NIS biogeography. Similar east to west patterns of other NIS taxa have also been noted (Cohen and Carlton 1995, Leppakoski and Olin 2000, Miller and Chapman 2000). Moreover, the patterns of NIS invasions must correspond to climate patterns if climate is an important ecological and evolutionary mechanism controlling the geography species.

The correlations between marine and estuarine peracaridan NIS invasions with temperature and salinity conditions may reveal where, and perhaps how, climates control NIS distributions. NIS peracaridans are unlikely to be as suited to local climates as native species that have had more evolutionary time to adapt. From a maximum possible of 3, the average occurrence of NIS between San Francisco Bay, Puget Sound and Prince William Sound is 1.4 compared to 1.8 records per native species (Table 9C4.2). This restriction of NIS peracaridan distributions in the northeast Pacific relative to native peracaridan species may result from their different adaptations to climate. NIS peracaridan dispersal vectors are sufficient to move NIS peracaridans to Prince William Sound. Port Valdez is the third largest ballast water port in the U.S. and the associated nonindigenous ballast water species that it receives are diverse and abundant (Hines *et al.* 1999) but none of these peracaridan species have been discovered in Prince William Sound. At the same time, the same nonindigenous ballast water species are invading San Francisco Bay at an accelerating rate (Cohen and Carlton 1998). The greater diversity of NIS in San Francisco Bay (Figure 9C4.1), the complete overlap between Puget Sound NIS and San Francisco Bay NIS and the absence of NIS in the Prince William Sound collections (Table 9C4.1), indicate that peracaridans have warm water origins and survive poorly in the cold-water areas of the northeast Pacific.

The introductions of *Corophium volutator* and *Orchestia gammarellus* (Table 9C4.2) from Europe to eastern North America are exceptions to the western ocean to eastern ocean pattern of introductions listed here. *Corophium volutator* is confined in North America to the Bay of Fundy. *Orchestia gammarellus* is confined in North America to the Bay of Fundy and the outer coasts north to Newfoundland (Bousfield 1973, Watling 1979). The climates of these areas are isolated from the Gulf Current and have narrower temperature ranges than areas either to the north or south (Bousfield 1973). The successes of these two species, and other European species such as the green crab *Carcinus maenus* and the European littorine snail *Littorina littorea* in this region, and the Bay of Fundy in particular, may result from the closer match between the climate of this region and the climate of northern Europe.

The occurrence of 5 NIS species of amphipods in segregated ballast water of tankers discharging into Port Valdez indicates that this is an active mechanism of transport introducing NIS arriving to Prince William Sound, even though none of these species appears to have become established yet.

Conclusions

These results reveal that climate and evolution interact to prevent estuarine peracaridan NIS from invading south central Alaska. Western ocean introductions of peracaridans to eastern ocean estuaries are common while few eastern ocean peracaridan species spread in the opposite direction. Unless Arctic Ocean passages of ballast water from the north Atlantic become possible, or global climate changes significantly, or massive shipping from high latitudes of the southern hemisphere occurs, ballast water sources NIS peracaridans from climates similar to south central Alaska are too remote to pose a significant risk.

Like a lock and key, the adaptations of successful invaders must be sufficient to survive in climates and types of disturbances that occur in the new invaded areas. Thermal adaptations of western ocean species may thus fit eastern ocean climates while the thermal adaptations of most eastern ocean species may be insufficient for western ocean climates. By the same mechanism, seasonal salinity disturbances may confine western ocean NIS peracaridans in eastern ocean estuaries to areas where the most stable salinity conditions occur and control which taxonomic groups of NIS peracaridans predominate in particular estuaries. This pattern of invasion appears to be consistent among many taxa even though the particular interacting mechanisms of climate and adaptation creating the pattern remain unresolved and the particular species that invade remain unpredictable. However, predicting where species can survive provides a means to identify, particular mechanisms of introduction, source regions for NIS of greatest concern, the likely secondary dispersal routes of newly introduced species and the possible role of climate changes on further invasions.

Seasonal temperature variations are difficult for shallow water organisms to avoid. The extreme high and low temperature ranges of western ocean climates (Figures 9C4.4 and 9C4.5) create adaptations that span most eastern ocean temperature ranges. The reverse is less likely and must prevent survival of many western ocean introductions of eastern ocean species. The entire sea surface temperature range of the northeast Pacific between 35 and 50° N is overlapped by the temperature ranges of the western ocean coasts between 37 and 42° N (Figure 9C4.6).

Thermal limits for the NIS peracaridans at 60° N (Prince William Sound) are apparent also for the Pacific oyster, *Crassostrea gigas* (Thunberg, 1795), native to the western Pacific and cultured commercially in Asia as far north as Hokkaido, Japan (Quayle, 1969) at about 44° N. *Crassostrea* grows but does not spawn in the low temperatures of Prince William Sound or south central Alaska (Foster 1991, Hines and Ruiz 1997). The minimum monthly temperatures of Prince William Sound match western Atlantic and western Pacific minimum temperatures as far south as 44° N (Figure 9C4.6). Thus, lethal low temperatures might not be encountered in the sound by western ocean NIS peracaridans from 44° N or even slightly farther south. However, maximum northeast Pacific sea surface temperatures at 60° N match western Atlantic and western Pacific maximums only as far south as 48° N (Figure 9C4.6) the inability of *C. gigas* to spawn in Alaska is therefore not surprising.

The poor match of seasonal precipitation across oceans (Figures 9C4.4 and 9C4.5) may also affect the patterns of introduction. The range of coinciding temperature and salinity tolerances that peracaridan species require to survive and reproduced in south central Alaska may prohibit NIS peracaridans that also survive in Long Beach, San Francisco or Puget Sound. The low summer salinities in Prince William Sound (Hines and Ruiz 1997) due to snow melt, more closely matches a western ocean climate (Figures 9C4.4 and 9C4.5). Only the largest eastern ocean estuaries or estuaries with impounded freshwater sources, such as San Francisco Bay, are likely to have stable haloclines in summer that match those of western ocean estuaries.

The high diversity and predominance of benthic peracaridan NIS in the northeast Pacific (Table 9C4.1) may result in part from their superior adaptive responses to large salinity ranges

(Figure 9C4.6). All peracaridan life stages are highly mobile, and their short reproductive cycles allow dispersal away from unsuitable conditions and rapid recruitment when conditions improve (*e.g.*, Watkin 1941). Peracaridans can avoid rapid changes in salinity (Figures 9C4.4 and 9C4.5) by migrating short vertical distances or by swimming into water masses in which transport them to higher or lower salinity areas.

San Francisco Bay may be particularly suited to NIS peracaridans that cannot avoid or quickly adapt to changing salinities. The particular predominance and high diversity of large, long-lived, suspension feeding NIS in San Francisco Bay (Carlton 1979, Nichols *et al.* 1990, Thompson 1998) may result from human water impoundments that limit major freshwater runoff events. San Francisco Bay is the largest estuary of the eastern Pacific. Massive water diversions and impoundments in the San Francisco Bay watershed, aided by its large size, create a stable salinity structure more typical of western ocean estuaries. Sedentary, long-lived species, including molluscs (Nicholls *et al.* 1990), burrowing decapods (Posey *et al.* 1991, Grosholz and Ruiz 1995, Cohen and Carlton 1997) and sedentariate polychaetes (Pearson and Rosenberg 1978) predominate in benthic communities in the absence of major salinity disturbances. These taxa can control the trophic dynamics in estuaries (Nichols *et al.* 1986, Kimmerer *et al.* 1994, Barber 1997, Thayer *et al.* 1997, Thompson 1998) but are slow to repopulate areas following disturbances.

The vulnerability of estuaries to invasion and the potentials of particular taxa and life history types to become invasive may be increasing globally and increase the risk of NIS invasions of Alaskan waters in the future. Water diversions and impoundments and land use practices on western coasts combined with global temperature increases are reducing the differences between climates of eastern and western ocean estuaries. The convergence of climates will increase the potential for biological exchanges.

The predominantly western ocean to eastern ocean direction of peracaridan invasions and south to north gradient in peracaridan invasions support a lock and key hypothesis in which peracaridan NIS cannot be introduced outside of their tolerance ranges. Obvious predictions of this hypothesis that should be tested are: 1) sources of eastern ocean invaders are from a narrow range of western ocean latitudes; 2) eastern ocean invaders of western oceans have restricted geographical ranges; 3) specific physiological tolerances and life history adaptations of most NIS exceed the stresses experienced in the climates invaded; 4) southern hemisphere NIS invasions superimpose on and are superimposed upon by northern hemisphere NIS when their origins are from similar climates; 5) climates affect the life histories and taxonomic composition of invaders and; 6) invaders of western to western or eastern to eastern oceans have broader ecological and geographical ranges than mixed climate invaders.

The analysis of climates and the geography of introductions must include more species and taxa in more detail than is possible here. However, failure to determine the origins of the cryptogenic peracaridan species (Table 9C4.1) are a more critical short-coming of this risk analysis. The eight cryptogenic peracaridans are abundant over broad ecological distributions within the south central Alaska. Even though none of the cryptogenic peracaridan species

appear to be associated with ballast water as a means of introduction, these species are abundant and wide spread. If introduced, they are proof that even a few NIS invaders of Alaskan estuaries can increase to ecologically catastrophic densities. Moreover surveys of NIS diversity, such as this one, are an insufficient for estimating ecological risks if these species are introduced. Due to the potential for a single species to produce massive impacts, conclusions of risk from global patterns of diversity of diversity and climate therefore could conflict with conclusions of risk based on presence of even a single NIS in a system. The occurrence of 5 NIS species of amphipods in segregated ballast water of tankers discharging into Port Valdez indicates that this is an active mechanism of transport introducing NIS arriving to Prince William Sound, even though none of these species appears to have become established yet.

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Appendix Table 9C4.5. Site Descriptions

1999 PRINCE WILLIAM SOUND NIS SURVEY ITINERARY AND GENERAL SITE DESCRIPTIONS

DATE	AREA	SITE	LOCATION	LAT/LON	TEMP (°C)	SAL (0/00)	DESCRIPTION
Aug 8	Homer	1	Homer Boat Harbor Floats	61° 05' 12"N 146° 23' 30"W	10	27	Cement floats
Aug 8	Homer	2	Homer, harbor benthos grab	61° 05' 10"N 146° 22' 28"W	10	27	Dense plant debris, anoxic
Aug 8	Homer	3	Homer Mudflats	61° 05' 10"N 146° 21' 55"W	10	27	Rock/cobble intertidal wash
Aug 9	Seward	4	Seward Floats and benthic grab	61° 04' 54"N 146° 19' 00"W	11	7	Cement floats and silt benthos
Aug 9	Seward	5	Seward Lowell Point	60° 52' 55"N 146° 46' 29"W	11	11	Rock/cobble intertidal.
Aug 10	1	6	Whittier Harbor	60° 46' 37"N 148° 41' 24"W	11	23	Floats and benthic grab
Aug 10	2	7	Shotgun Cove Fouling	60° 47' 26"N 148° 32' 30"W	12	9	Fouling on oil-barge mooring buoy
Aug 11	3	8	Fairmont Bay Oyster floats	60° 53' 40"N 146° 26' 03"W	14	25	Fouling on oyster float, nets and line
Aug 11	4	9	Duckflat & Port Valdez Harbor	61° 07' 28"N 146° 18' 00"W	10	5	Mudflat of sparse <i>Zostera</i> , shallow pools, and small meandering intertidal stream
Aug 12	5	10	Cloudman Bay, Busby Is Mudflats and <i>Zostera</i>	61° 03' 23"N 146° 47' 25"W	13	14	Mudflat of dense <i>Zostera</i> , split by glacial-fed stream
Aug 12	6	11	Busby Reef High rocky intertidal	60° 57' 36"N 146° 45' 36"W	15	19	Rock and cobble wash
Aug 13	7	12	Cordova Harbor 1 & 2	60° 52' 12"N 146° 43' 48"W	13	24	Low intertidal mudflats with shell & rock Highly polluted
Aug 13	7	13	Cordova Harbor #4	60° 41' 47"N 145° 57' 22"W	20	0	Compacted silt above creek drainage

(SITE ITINERARY AND DESCRIPTION CONTINUED)

Appendix Table 9C4.5. Continued

DATE	AREA	SITE	LOCATION	LAT/LON	(°C)	(0/00)	DESCRIPTION
Aug 13	7	14	Cordova #5	60° 40' 21"N 145° 57' 06"W	20	11	Mud / silt bank next to drainage channel
Aug 13	7	15	Cordova #6	60° 32' 30"N 145° 46' 28"W	15	0	Creek bed cobble upper edge mudflat
Aug 13	7	16	Cordova Harbor	60° 32' 28"N 145° 46' 28"W	11	20	Benthic grabs, anoxic sediments
Aug 13	7	17	Cordova Harbor Benthic grab	60° 32' 48"N 145° 46' 27"W	12	28	Anoxic mud
Aug 13	7	18	Cordova Harbor Floats	60° 32' 27"N 145° 46' 26"W	16	5	Rocky intertidal
Aug 13	8	19	Green Buoy "12" Cordova Harbor entrance	60° 32' 40"N 145° 45' 59"W	11	22	Fouling
Aug 13	9	20	Windy Bay, Hawkins Is.	60° 33' 54"N 145° 58' 38"W	14	28	Fouling on oyster float, nets and line
Aug 13	10	21	Red Buoy "2" Middle Ground Shoal, Hinchbrook	60° 32' 52"N 146° 22' 06"W	14	28	Drift Zostera
Aug 14	11	22	Constantine Harbor Hinchbrook Is.	60° 20' 25"N 146° 37' 00"W	11	30	

Appendix Table 9C4.6. Peracardian Crustacea August 1999

South Central Alaska Fouling survey Homer, Seward and Prince William Sound, August 6-16, 1999

Area Site	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	
General location	Homer	Homer	Homer	Seward	Seward	Whittier	Shotgun Cove	Fairmont Bay	Vakdez	Cloudman Bay	Busby Is.	Cordova	Cordova	Cordova	Cordova	Cordova	Cordova	Cordova	Cordova	Windy Bay	Md. Gmd	Constantine	
Specific location	floats		Harbor	Benthos floats	Rocky-Pt. rocks	Floats Benth	mooring buoy	Oyster nets	Mudflats cobble	mudflats Zostera	rocks cobble	high tide mud pool	Mudflat 1&2	mudflat #4	mudflat #5	mudflat #6	benthos benth grab	Harbor floats	entrance Buoy "12"	oyster net	Shoal Buoy "2"	Harbor Benthos	
Substratum	cobble	mudflat	benth grb	floats	rocks	Benth	buoy	nets	cobble	Zostera	cobble	mud pool	1&2	#4	#5	#6	benth grab	floats	Buoy "12"	net	Buoy "2"	Benthos	
Collection Date	08-Aug-99	08-Aug-99	8-Aug-99	08-Aug-99	09-Aug-99	10-Aug-99	10-Aug-99	11-Aug-99	11-Aug-99	12-Aug-99	12-Aug-99	13-Aug-99	13-Aug-99	13-Aug-99	13-Aug-99	13-Aug-99	13-Aug-99	13-Aug-99	13-Aug-99	13-Aug-99	13-Aug-99	14-Aug-99	
Mysidacea																							
<i>Mysis littoralis</i>																							X
Tanaidacea																							
<i>Leptochelia savignyi</i>											X												
Isopoda																							
<i>Gnorimosphaeroma lutea</i>																X							
<i>Gnorimosphaeroma oregonensis</i>		X		X	X	X			X		X												X
<i>Ianiropsis kincaidii</i>											X												
<i>Idotea obscura</i>					X																		X
<i>Idotea wosSENSkii</i>				X	X	X			X		X							X					
<i>Ligia pallasii</i>									X														
<i>Limnona lignorum</i>																							X
Cumacea																							
<i>Cumella vulgaris</i>		X							X		X		X										X
<i>Diastylis alaskensis</i>			X										X										
<i>Lamprops beringi</i>					X																		
<i>Lamprops quadriplicata</i>			X																				
Gammaridea																							
<i>Ailorchestes angusta</i>						X			X				X						X				X
<i>Americorophium brevis</i>																							X
<i>Americorophium salmonis</i>													X	X	X								
<i>Americorophium spinicome</i>			X												X								
<i>Amphithoe kussakini</i>		X			X	X	X				X		X										X
<i>Amphithoe sectimanus</i>	X																						
<i>Amphithoe sp.</i>									X														
<i>Anisogammarus pugettensis</i>		X		X	X								X										
<i>Aoroides sp.</i>			X																				
<i>Calliopeia sp.</i>						X			X										X				
<i>Calliopius caninatus</i>					X																		X
<i>Eogammarus confervicolus</i>						X			X	X						X	X						X
<i>Eogammarus oclairi</i>				X																			
<i>Hyale frequens</i>												X											
<i>Hyale plumukosa</i>												X											
<i>Ischyrocerus sp.</i>								X															
<i>Jassa stauderi</i>										X													
<i>Lagunogammarus setosus</i>				X					X	X	X		X				X			X	X		
<i>Locustogammarus locustoides</i>	X	X			X																		
<i>Megamorea subtener</i>													X										
<i>Monocorophium carlottensis</i>	X			X		X		X					X										X
<i>Paramoera bousfieldi</i>									X									X					X
<i>Paramoera mohri</i>					X																		
<i>Peramphithoe humeralis</i>																				X			
<i>Peramphithoe mea</i>	X																						
<i>Pontogeneia ivanovae</i>					X																		
<i>Pontogeneia rostrata</i>	X					X																	
<i>Pontoporeia femorata</i>									X														X
<i>Spinulogammarus subcannatus</i>		X			X				X														
Caprellidea																							
<i>Caprella depranochir</i>													X										X
<i>Caprella laeviuscula</i>	X						X			X													
<i>Caprella sp.</i>		X									X												
<i>Metacaprella kenerlyi</i>										X			X						X				

Appendix Table 9C4.7. UAF unidentified Amphipoda

University of Alaska Museum unidentified Amphipod collections examined, 1999

Site	ST	TR	QD	Sample	Date	UAFID	<i>Monocorophium carlottensis</i>	<i>Megamoera dentata</i>	<i>Ampithoe kussakini</i>	<i>Ampithoe</i> sp.	<i>Limnoria lignorum</i>
26	1	3	1	A-7	07/11/91	Corophium sp.	1				
26	1	3	2	A-8	07/11/91	Corophium sp.	3				
26	1	3	2	A-8	07/11/91	Corophium sp.					
15	3	3	2	136-138	02/24/93	Corophium sp.	5				
15	3	1	2	119-121	07/24/93	Corophium sp.	2				
26	2	1	2	14(3)		Melita sp.		3			
15	1	3	2	137	07/24/91	Corophium sp.	24				
15	1	3	2	137	07/24/91	Corophium sp.					
15	3	3	2	141		Corophium sp.	3				
14	3	3	2	105-106	07/23/93	Corophium sp.	10				
15	2	3	1	129-130	09/24/93	Corophium sp.	2				
15	3	1	2	119-121	07/24/93	Melita sp.		3			
34	3	5	2	65		Ampithoe sp.			3		
26	1	1	1	1	07/11/91	Melita sp.		1			
111	3	3	1	47-48		Corophium sp.	1				
18	1	1	1	156	02/07/91	Melita sp.		1			
11	3	3	2	49-50		Limnoidae					1
15	3	3	1	140	07/24/91	Corophium sp.	3				
34	2	3	2	63	07/15/91	Ampithoe sp.			6		
14	2	3	2	101-102	07/23/93	Ampithoe sp.				2	
26	3	3	2	12	07/11/91	Corophium sp.	2				
15	2	3	1	138		Ampithoe sp.			1		
15	3	3	2	141		Ampithoe sp.				1	
34	3	3	2	65		Corophium sp.	35				
15	1	3	2	125-128	07/24/93	Corophium sp.	13				
15	1	1	1	107-108	07/24/93	Melita sp.		3			
15	1	1	1	107-108	07/24/93	Melita sp.					
15	1	3	1	123-124	02/24/93	Ampithoe sp.			4		
15	2	1	1	112-113	07/24/93	Melita sp.		1			
14	3	3	2	105-106	07/23/93	Melita sp.		3			
14	3	3	2	105-106	07/23/93	Melita sp.					
14	3	3	2	105-106	07/23/93	Ampithoe sp.				1	
26	2	3	1	9		Corophium sp.	1				
18	2	3	1	165	07/28/91	Corophium sp.	3				
15	1	1	1	127	07/23/91	Corophium sp.	1				
15	2	1	1	129		Corophium sp.	10				
15	2	1	1	129		Melita sp.					2
15	2	1	1	129		Melita sp.					
RBA 1-3 UAH					09/02/82	Limnoria lignorum					1

Aquatic Coll. 1994-5 Rocky Bay, Montague Is. PWS HY033 RBA001 72 m

APPENDIX TABLE 9C4.8 Descriptions of Amphipod Species Identified in Ballast Water Tanks.

Hyperidae

Hyperidae

Hyperia cf. *medusarum* (Bowman 1973:6-10, figs. 2-6 and references therein; Brusca 1981:21, fig. 9e; Vinogradov et al. 1996:323-327, fig. 131 and references therein). *Hyperiaa medusarum* is a morphologically variable bipolar pelagic species of cold and moderately cold water marine regions of both hemispheres, occurring in the Bering Sea, the Gulf of Alaska and the coastal waters of Canada and the western U. S. (Vinogradov et al. 1996). Specimens of this study are all less than 4 mm in length, and none are mature. Gnathopods, mandibles and pereopods closely resemble *H. medusarum* but the identifications are tentative. The sutures between pereonites 1 and 2 and between coxal plates and pereonites are faint. Their appearance only in the Anacortes samples and in the open ocean exchanged ballast water samples (Table 1) are consistent with the life history of typical hyperiids and this species is very likely native to the region.

Gammaridea

Ampeliscidae

Ampelisca abdita Mills, 1964a; Northeast Pacific records of *Ampelisca milleri* are: Jones 1961:253-254; Filice 1959a:183; Filice 1959b:10; Chapman and Dorman 1975:107, 106; Chapman 1988:365-368, fig. 2 (and references therein); Dickensen 1982:15-17, fig. 9; (not Barnard 1954b:9-11). The range of *A. abdita* on the east coast of the U.S. extends from Maine to the eastern Gulf of Mexico (Mills, 1967, Bousfield 1973, Chapman 1988).

Ampelisca abdita from San Francisco Bay, Bolinas Lagoon and Tomales Bay was confused with *Ampelisca milleri* Barnard 1954 for 40 years and was probably introduced into San Francisco Bay from the eastern U. S. with shipments of the eastern oyster *Crassostrea virginica* (Chapman 1988). The species dominates soft, subtidal sedimentst's of San Francisco Bay at salinities between 10 and 25 PSU and must occasionally occur as zooplankton in massive numbers as it seasonally exits and repopulates shallow subtidal an intertidal mudflats (Mills 1967).

Argissidae

Argissa hamatipes (Norman 1869); *Syrrhoe hamatipes* Norman 1869:279; Boeck 1871:125; *Argissa stebbingi* Bonnier 1896:626-630, pl.36, fig.4; *Argissa typica* Sars 1895:141-142, pl.48; Chevreux & Fage 1925:90, figs.81-82; Ruffo 1982:159-161, figs. 106-107; *Argissa hamatipes* Walker 1904:246; Stebbing 1906:277; Shoemaker 1930:37-40, figs.15-16; Stephensen 1935:140; Stephensen 1940:41; Stephensen 1944:52; Gurjanova 1951:327-328, fig.193; Gurjanova 1962:392-393; J.L. Barnard 1962c:151; J.L. Barnard 1964a:218-219; Nagata 1965:154-155, fig.7; J.L. Barnard 1966a:61; J.L. Barnard 1967a:14-15, fig.1d-i; J.L. Barnard 1969b:159, fig. 65; J.L. Barnard 1971b:9; Bousfield 1973:121-122, pl.XX; Griffiths 1975:; Lincoln 1979:334, fig.157; Ledoyer 1982:144-146, fig. 50; Hirayama 1983:147-149, figs.38-41; Barnard & Barnard 1983:607-608; Thomas & McCann 1997:22, fig.2.1.

Argissa hamatipes is an entirely marine, nearly cosmopolitan species with an extensive bathymetric distribution that ranges throughout coastal north Pacific shelf regions from southern California to southern Japan and the north Atlantic from North Carolina Greenland and Iceland,

throughout northern Europe and the western Mediterranean, Madagascar and South Africa. Many of the the synonymies are unclear. This extremely dispersed species is likely to be a species complex and the identity of the North Pacific population is probably incorrect. Nevertheless, the very broad open ocean distribution in the northeast Pacific population strongly indicates that it is a native to the region.

Corophiidae

Monocorophium acherusicum *Podacerus cylindricus* Lucas 1842:232; *Corophium cylindricum* Smith 1873:566; Paulmier 1905:167, fig. 37; Holmes 1905:521-522, fig. ; ?*C. cylindricus* Stebbing 1914:372-373; Kunkel 1918:171-173, fig. 52; *Corophium contractum* Thompson 1881:220-221, fig. 9; *Corophium bonnellii* K. H. Barnard 1932:244 (in Crawford 1937); *Corophium acherusicum* 1853:178; Costa 1857:232, Fig. 1827; Bate 1862:282; Heller 1867:51-52, pl 4 fig. 14; DeElla Valle 1893:364-367, pl. I, Fig. II, Pl. 8, figs. 17, 18, 20-41; Sowinsky 1897:9; Sowinsky 1898:455; Chevreux 1900a:109; Graeffe 1902:20; Holmes 1905:521-522, fig. ; Stebbing 1906:692-740; Chevreux 1911:271; K. H. Barnard 1916:272-274; Stebbing 1917a:448; Ussing and Stephensen 1924:78-79; Chevreux 1925c:271; Chevreux and Fage 1925:368, fig. 376; Chevreux 1926:392; Cecchini 1928e:8, pl. 1, fig. 6a; Cecchini 1928b:309-312, fig. 1; Schellenberg 1928:672; Schijfsma 1931a:22-25; Monod 1931a:499; Fage 1933:224; Candeias 1934:3; Shoemaker 1934c:24-25; Cecchini-Parenzan 1935:227-229, fig. 52; Shoemaker 1935c:250; Crawford 1936:104; Schellenberg 1936c:21; Schijfsma 1936:122-123; Crawford 1937:617-620, 650, fig. 2; Monod 1937:13; Miloslavskaya 1939:148-149; K. H. Barnard 1940:482; Bassindale 1941:174; Stephensen 1944a:134; Shoemaker 1947:53, figs. 2, 3; Shoemaker 1949a:76; Soika 1949:210-211; Gurjanova 1951:977-978, fig. 680; Reid 1951:269; Stock and Bloklader 1952:4-5; J.L. Barnard 1954a:36; Hurley 1954e:442-445, figs. 35-39; J. L. Barnard 1955a:37; Irie 1957:5-6, fig. 6; Irie 1958c:145; Irie 1959: tab. 4; J.L. Barnard 1959:38; Nayar 1959:43-44, pl. XV, figs. 14-20; Irie In Okada and Ochida et al. 1960:122, pl. 61, fig. 12; Nagata 1960:177; J. L. Barnard 1961:182; Irie and Nagata 1962:20; Nagata 1964:10; Barnard 1964a:111, chart 5; Nagata 1965c:317; Nagata 1966:334; Kikuchi 1966:, tab 21; Kikuchi 1968:179; Reish and J. L. Barnard 1967:16; Ledoyer 1968:214; Fearn-Wannan 1968b:134-135; Mordhukai-Boltovskoi 1969:485, pl. 25, fig. 2; Sivaprakasam 1969d:156, fig. 14; Bellan-Santini 1971:260-261; J. L. Barnard 1971a:59; J. L. Barnard 1972b:48; Bousfield 1973:201, Pl. LXII.2; Griffiths 1974:181-182; Griffiths 1974b:228; Griffiths 1974c:281; Griffiths 1975:109; Fox and Bynum 1975:225; Hirayama 1984:13, fig. 50; Azuma 1986:77; Sudo et al. 1987:1570; Inaba 1988:141; *Monocorophium acherusicum* Bousfield and Hoover 1997:111-114, figs. 26-27.

Monocorophium acherusicum could be the most widely distributed and widely introduced estuary invertebrate in the world, occurring in fouling and benthic mud communities of shallow and intertidal areas on all continents except Antarctica. *C. acherusicum* has been reported at all latitudes between 60° North and South. However, many of the records of this species at latitudes greater than 60°, including all records from Alaska are doubtful (Hines et al. 1999) due likely confusion with other species. *M. acherusicum* was not found in the present surveys of south central Alaska, including Port Valdez and Prince William Sound. Parthenogenic populations of an extremely similar species, that closely resembles *Monocorophium carlottensis* Bousfield and Hoover, 1997, occurs in nearly all fouling communities of these areas (Chapman 1999, Peracarida and Decapoda). All Alaskan records of

the nonindigenous species, *M. insidiosum* and *M. acherusicum* are probably referable to *M. carlottensis*.

Sinocorophium heteroceratum (Yu, 1938) *Corophium heteroceratum* Yu 1938:93-101, figs. 7-11; *Sinocorophium heteroceratum* Bousfield and Hoover 1997:75, 78.

Sinocorophium heteroceratum was introduced into San Francisco Bay and Los Angeles Harbor from Asia in the mid 1980s where it presumed to have been transported with ballast water traffic (Cohen and Carlton 1995). This species occurs predominantly in soft sediments in high salinity, sub-tidal areas of San Francisco Bay and Los Angeles Harbor (Chapman and Cole, MS in preparation). *Sinocorophium heteroceratum* are also unlikely to have been introduced with aquaculture industries, or ship fouling in San Francisco Bay or Los Angeles Harbor because its lack of association with fouling communities.

Grandidierella japonica Stephensen, 1938:179-184; Nagata 1960:179; Nagata 1965c:320-321; Chapman and Dorman 1975:104-108, 4 figs., Nagata 1984:15, fig. 53-56; Muir 1997; Smith et al. 1999:8-9, fig. 3.

Grandidierella japonica occurs in salinities from 5-40 PSU predominantly in warm intertidal areas of nearly all estuaries from Puget Sound to San Diego. Dense populations are especially common in low-salinity tidepools and seepage areas; mixed sediment. The species has been introduced to Hawaii (Muir 1997) England (Smith et al. 1999), and estuaries of the northeast Pacific between Puget Sound and San Diego (Chapman and Dorman 1975, Staude 1997, Bay et al. 1988). *Grandidierella* was most likely introduced to the northeast Pacific with Pacific oysters from Japan between the 1930s and 1950s (Chapman and Dorman 1975). Its recent arrival in Europe (Smith et al. 1999) is more likely to be associated with ballast water. It was misidentified in Hawaii for 25 years as *Neogamphopus cabinae* (Muir 1997) where the mechanism of its introduction is unclear. The massive ballast water traffic from San Francisco Bay to Hawaii is a possible mechanism for its introduction there.

Cyphocharidae

Cyphocharis challengerii Stebbing 1888: ;Birstein and Vinogradov 1955:212 (with references); J. L. Barnard 1961b:31; Bowman and McCain 1967:1-14, figs. 1-9 (with references).

The most common epipelagic gammaridean amphipod in sub-Arctic offshore and coastal waters of the North Pacific is *Cyphocharis challengerii* (Bowman and McCain 1967). Bousfield and McCain (1967) demonstrated that most of the variation in the anterior protrusion of pereonite 1 varies with size. The species is endemic to the North Pacific but has been reported from a broad range of latitudes in the Atlantic and Indian Ocean. .

Eusiridae

Pontogeneia rostrata Gurjanova, 1938; Gurjanova, 1938:330,398, fig.39; Gurjanova, 1951:719, fig.500; Nagata 1960:171-173, pl.14; J.L.Barnard, 1962b:81; J.L.Barnard, 1964b:114-116, fig.20; Nagata 1965b:185, fig. 26; Nagata 1965e:563; Nagata 1966:334; J.L.Barnard, 1969a:111,112,114; Itoh 1970:29; Mukai 1971:178; Itoh, Honma and Kakimoto 1972:25; Honma and Kitami 1978:40; Azuma 1980:28; Barnard 1979a:49, figs. 25-27 (part); Imada et al. 1981:127; Itoh 1981:24; Itoh, Honma and Kitami 1982:41; Hirayama 1985a:28; Azuma et al. 1985:4; Azuma 1986:74; Sudo et al. 1987:1570; Inaba 1988:146; Ariyama 1988:129, fig. 13f; Barnard and Karaman 1991:334; Ishimaru 1994:45.

A widely reported species in the North Pacific from Bahia de San Quintin, Mexico (Barnard 1964) to Alaska and down the Asian coast to southern Japan (Ishimaru, 1994). *Pontogeneia rostrata* was recovered in the nonindigenous species surveys of Prince William Sound (Hines 1999). However, *P. rostrata* can easily be confused with species of *Accedemorea* its extremely broad range in the Northeast Pacific and uncertain taxonomic status prevents clear resolution of whether it is endemic or introduced. This species is cryptogenic (Carlton 1996).

Gammaridae

Gammarus daiberi Bousfield, 1969; Bousfield 1969:10(1)4-8, figs. 1& 4; Bousfield 1973:52, pl. IV.2; Toft et al. 1999:36.

A probable 1980s ballast water introduction into San Francisco Bay from the eastern United States. *Gammarus daiberi* is an estuarine species most abundant in the low salinity ranges between 1.5 and 15 PSU and is largely pelagic. Except for this report, this species is unknown in the northeast Pacific outside of San Francisco Bay. Its range in the eastern U.S. extends from Delaware Bay to South Carolina (Bousfield 1973). *Gammarus daiberi* is a probable ballast water introduction into San Francisco Bay that arrived in the 1980s.

Eogammarus confervicolus *Mara confervicola* Stimpson 1856:90; *Gammarus confervicolus* Stimpson 1857:520-521; Bate 1862:218, pl. 38, fig. 9; Holmes 1904:239; *Melita confervicola* Stebbing 1906:428; *Anisogammarus confervicolus* Saunders 1933:248 (in part); J.L. Barnard 1954a:9-12, pls.9-10; Shoemaker 1964:423, figs. 14-15; Pamamat 1968:211; Bousfield and Hubbard 1968:3; *Anisogammarus (Eogammarus) confervicolus* Schellenberg 1937a:274; Tzvetkova 1975:145-147, fig. 57; Bousfield 1958a:86, fig. 10; *Eogammarus confervicolus* Bousfield 1979:317-319, fig.4.

Eogammarus confervicolus is the only native species recovered from ballast water that was also collected in the Prince William Sound nonindigenous species survey (Chapman 1999). *Eogammarus confervicolus* is extremely euryhaline and is occasionally pelagic. It occurs mainly in estuaries and protected coastal shores. *Eogammarus confervicolus* is the most common and widely distributed gammaroidean amphipod of the North American Pacific coast (Bousfield 1979).

Megaluropidae

Gibberosus longimerus Hoek; *Megaluropus longimerus*; J.L.Barnard 1962b:103, figs.20-21; J.L.Barnard, 1964a:224; J.L. Barnard 1966b:19; J.L.Barnard, 1969a:126; J.L. Barnard 1971b:15; *Gibberosus myersi* (McKinney 1980); *Megaluropus myersi* McKinney 1980; *Megaluropus longimerus* of Cadien *et al.* NEP (in part); (not Schellenberg 1925:151-153, fig.14).

The genus is poorly studied north of northern California (Cadien et al. 1997). Schellenberg (1925) figured only two appendages from his specimens from Lagos, Nigeria and the type specimens have not been compared to California material. The possibility of these populations comprising a single species seems remote. The common occurrence of this species over a broad range of coastal and nearshore waters (Barnard 1962) indicates that it is endemic.

Melphidipiidae

Melphisana bola Barnard 1962b:81-82, fig.7; Thomas & McCann 1997:42, fig.2.20.

This native species is limited to depths no greater than 130 m on the southern California coastal shelf (Barnard 1962b, Thomas and McCann 1997). Appendages are usually missing this species on recovery from benthic samples (Barnard 1962b, Thomas and McCann 1997) greatly

complicating identifications. These specimens are in excellent condition is in sharp contrast of previous material on which the species is described.

Oedicerotidae

Hartmanodes hartmanae *Monoculodes hartmanae* J.L. Barnard 1962:363, figs. 6-7; Barnard & Karaman 1991:560; *Hartmanodes hartmannae* Bousfield & Chevrier 1996:92-93, fig. 10. Bousfield and Chevrier (1996) did not find this species in their 200 samples from the shelf benthos and coastal waters of Canada and it is not listed in by Staude (1997). This species is native to southern California marine waters where it occurs at less than 40 m depths (Barnard 1962). *Hartmanodes hartmannae* is the most abundant gammaridean amphipod found in the samples.

Westwoodilla caecula *Halimedes caecula* Bate 1857:140; *Halimedes Mulleri* Boeck 1871:169-170; *Halimedes Mulleri* Sars 1895:327-329, pl.115; *Halimedes acutifrons* Sars 1895:329-330, pl.116, fig.1; *Westwoodilla caecula* Enequist 1950:333-338, figs.40-56; Gurjanova 1951:541-543, pl. 357; Mills 1962:5-9, fig.1; J.L. Barnard 1962e:370; J.L. Barnard 1964a:235; J.L. Barnard 1966a:80 (forma *acutifrons*); J.L. Barnard 1966b:27; J.L. Barnard 1971b:51; Lincoln 1979:354, fig.167; Thomas & McCann 1997:58, figs. 2.37, 2.38; Beare, D. J. and P. G. Moore 1998.

This species may not be part of a complex of similar species distributed around the Arctic Ocean, the Japan Sea, the north east Pacific from British Columbia to southern California and the North Atlantic from Greenland to the Gulf of St. Lawrence and northern Europe. This extremely widespread, common, species in offshore marine soft-sediment environments is most likely endemic to cold water areas of the northeast Pacific. Its occurrence in Port Valdez zooplankton samples is not surprising.

Synopiidae

Tiron sp.

The short dactyls, spineless telson, tiny mandibular palp, smooth dorsal urosome of this single specimen do not agree with either of the local species *Tiron tropakis* J. L. Barnard, 1972 or *Tiron biocellata* J. L. Barnard, 1962. Pelagic dispersal of benthic peracaridans usually occurs as adults and often is preceded by slight morphological changes that are adaptive for swimming. These changes are poorly understood. The low morphological correspondence of this single specimen with a known species is therefore not surprising. The specimen is therefore considered more likely to be a member of one of the above native species than an introduced species.

References for Appendix Table 9C4.8 (Descriptions of Amphipod Species Identified in Ballast Water Tanks:

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